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FOREWORD

Welcome to the 8th volume and issue number 1 of the ESTEEM Academic Journal UiTM (Pulau Pinang): a peer-refereed academic journal devoted to all engineering disciplines. This issue of journal sees a new Chief Editor and marks the journal's first electronic publication. Using the e-journal inauguration as an occasion, I would like to thank many people who created the opportunity for this e-journal to be born and who made it happen. First and foremost, I would like to extend my sincere appreciation and utmost gratitude to Associate Professor Mohd Zaki Abdullah, Rector of UiTM (Pulau Pinang), Associate Professor Ir. Bahardin Baharom, Deputy Rector of Academic Affairs and Dr. Mohd Subri Tahir, Deputy Rector of Research, Industry Linkages, Community & Alumni for their unstinting support towards the successful publication of this e-journal. Not to be forgotten also are the constructive and invaluable comments given by the eminent panels of external reviewers and language editors who have worked assiduously towards ensuring that all the articles published in this journal are of the highest quality. A special acknowledgement is dedicated to all committees, publication department, and many other relevant parties for making this journal a success. Their affective commitment and close cooperation have facilitated the realization of this journal. Last but not least, my greatest thanks go to all the authors for their interest in publishing with ESTEEM. Their manuscripts are an expression of their commitment towards research and development which, in due course, would benefit the local, national and international communities. Hence, I would like to extend my warm invitation to all researchers who are actively involved in the field of engineering to publish their work in ESTEEM.

Dr. Chang Siu Hua
Chief Editor
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2D FINITE ELEMENT ANALYSIS FOR DEFORMATION AND STABILITY OF BAMBOO REINFORCED EMBANKMENT

Aminaton Marto[1], Badrul Nizam Ismail[2], Ismail Bakar[3] and Bakhtiar Affendi Othman[4]

[1,4]*Faculty of Civil Engineering, Universiti Teknologi Malaysia, 81300 Skudai, Johor, Malaysia*
[2]*Faculty of Civil Engineering, Universiti Teknologi MARA (UiTM) Malaysia, 13500 Permatang Pauh, Penang, Malaysia*
[3]*Research Centre for Soft Soils (RECESS), Faculty of Civil & Environmental Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia*
[2]*badrulnizam@ppinang.uitm.edu.my*

ABSTRACT

The problem of soft clay is associated with low bearing capacity and high compressibility. The improvement and stabilization of these soils usually involve expensive soil improvement method. A research has been carried out on the use of locally available bamboo, laid in 1 m square pattern, for reinforcing the soft soil before a 3 m embankment was constructed. The bamboo reinforced embankment, constructed at the Research Centre of Soft Soils (RECESS), Universiti Tun Hussein Onn Malaysia (UTHM), was simulated using a two dimensional (2D) finite element analysis. The purpose of this analysis is to evaluate the deformation and stability of the embankment. The evaluation of deformation and stability are important since the embankment is situated on the soft soil and consists of sloping surface at both sides. It is found that for deformation analysis, it is largely depends on the parameters of Soft Soil Creep model while for stability analysis, the performance of the model simulation largely depends on the parameters of Mohr-Coulomb model. The results from the analysis show that bamboo reinforced embankment performs better in terms of both stability and deformation.

Keywords: Mohr-Coulumb; soft soil creep; geotextile

1. INTRODUCTION

Soil stabilization of soft soils is very important in order to ensure development at certain area can be implemented. Normally, the problem of construction on soft soils is associated with low bearing capacity (related to strength) and high compressibility (related to stiffness). Several techniques of soil stabilization had been developed (such as physical and chemical methods) in order to improve the strength and stiffness of the soil. However, some of these methods require expensive cost, which require the engineers to think on cheaper method.

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In this study, a 3 m-height embankment that had been constructed at the Research Centre of Soft Soils (RECESS), Universiti Tun Hussein Onn Malaysia (UTHM), was simulated using a two dimensional (2D) finite element analysis. The software that had been used for this purpose is PLAXIS 2D. The purpose of this analysis is to evaluate the stability and deformation of the embankment. The constructed embankment was strengthened using three different methods, namely:

Trial Embankment 1 (TE1): High Tensile Strength Geotextile

Trial Embankment 2 (TE2): Bamboo with Geotextile (as separator)

Trial Embankment 3 (TE3): Geotextile (as separator)

2. SELECTION OF PARAMETERS

2.1 Soil Parameters

2.1.1 Fill Soil (Embankment)

Fill soil was modeled using Mohr-Coulomb model, since for stability analysis, the strength parameters is more significance compared to stiffness parameters. The parameters for fill soil are shown in Table 1. Data for strength parameters are taken from Mohd Hanipiah (2009).

Table 1: Parameters for Fill Soil

Parameter	Value	Unit
Dry unit weight, γ_{unsat}	15.2	kN/m^3
Bulk unit weight, γ_{sat}	19.1	kN/m^3
Horizontal permeability, k_x	0	m/day
Vertical permeability, k_y	0	m/day
Elastic stiffness, E	5000	kN/m^2
Poisson's ratio, ν	0.38	-
Cohesion, c	136.8	kN/m^2
Friction angle, φ	23.54	°

Since the strength parameters are obtained from unconsolidated undrained test, while the parameters that are necessary to simulate in PLAXIS 2D are drained parameters, it will be used, due to reason there is no drained triaxial test had been conducted. Furthermore, drained parameters will be higher than undrained parameters, so stability analysis will provide a lower value than the actual value.

2.1.2 Foundation Soil

Foundation soil was modeled using Soft Soil Creep model, since for deformation analysis, the stiffness parameters is more significance compared to strength parameters. The parameters for foundation soil are shown in Table 2. However, strength parameters is still significance, by considering the slope failure might still occur in upper layer of foundation soil and failure due to bearing capacity of soil.

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The stiffness parameters used in the analysis are modified parameters (taking into consideration the three dimensional effect). The data was obtained from several oedometer tests on the soil sample taken from the site at the depth up to 4 m. However, it has to be mentioned that the data is not really complete, as to properly model the embankment, it is necessary to have data for foundation soil from greater depth.

Table 2: Parameters for Foundation Soil

Layer 1 **Depth: 0 – 4.5 m**		
Parameter	Value	Unit
Dry unit weight, γ_{unsat}	14.5	kN/m^3
Bulk unit weight, γ_{sat}	19.0	kN/m^3
Horizontal permeability, k_x	$2.03\text{x}10^{-5}$	m/day
Vertical permeability, k_y	$2.03\text{x}10^{-5}$	m/day
Modified compression index, λ^*	0.057	kN/m^2
Modified compression index, κ^*	0.015	kN/m^2
Modified compression index, μ^*	$2.14\text{x}10^{-3}$	kN/m^2
Cohesion, c	1	kN/m^2
Friction angle, φ	25	°
Layer 2 **Depth: 4.5 – 22.5 m**		
Parameter	Value	Unit
Dry unit weight, γ_{unsat}	14.8	kN/m^3
Bulk unit weight, γ_{sat}	19.2	kN/m^3
Horizontal permeability, k_x	$2.03\text{x}10^{-5}$	m/day
Vertical permeability, k_y	$2.03\text{x}10^{-5}$	m/day
Modified compression index, λ^*	0.057	kN/m^2
Modified compression index, κ^*	0.015	kN/m^2
Modified compression index, μ^*	$2.14\text{x}10^{-3}$	kN/m^2
Cohesion, c	1	kN/m^2
Friction angle, φ	25	°
Layer 3 **Depth: 22.5 – 32 m**		
Parameter	Value	Unit
Dry unit weight, γ_{unsat}	17.3	kN/m^3
Bulk unit weight, γ_{sat}	20.6	kN/m^3
Horizontal permeability, k_x	$2.03\text{x}10^{-5}$	m/day
Vertical permeability, k_y	$2.03\text{x}10^{-5}$	m/day
Modified compression index, λ^*	0.057	kN/m^2
Modified compression index, κ^*	0.015	kN/m^2
Modified compression index, μ^*	$2.14\text{x}10^{-3}$	kN/m^2
Cohesion, c	1	kN/m^2
Friction angle, φ	25	°

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2.2 Bamboo Parameters

The bamboo was modeled using plate element. Embankment 2 which consists of both bamboo and geotextile, it was modeled separately, as the geotextile was modeled using geogrid element. The bamboos are modeled as an elastic material & the parameters for the bamboo are as shown in Table 3.

Table 3: Parameters for Bamboo Reinforcement

Parameter	Value	Unit
Axial stiffness, EA	2.225×10^4	kN/m
Flexural rigidity, EI	6.51	kNm^2/m
Weight, w	0.016	kN/m/m
Poisson's ratio, ν	0	-

The modulus of elasticity, E is taken as 16.06 GPa (bending modulus of elasticity at node), as it is the conservative value (lowest) and the governing stress in the bamboo when used as a reinforcement is bending stress.

The cross sectional area, A for one meter width of the plate is equivalent to cross sectional area of one bamboo, as the bamboo is spaced at one meter interval. Using average external diameter of 0.07 m and average thickness of 0.007 m, the area for one meter width of the bamboo is 1.39×10^{-3} m^2. Using similar assumptions, the moment of inertia, I for one meter width of the bamboo is 4.05×10^{-7} m^4.

The weight of the bamboo is taken as 0.016 kN/m/m, assuming specific gravity, G_s as 0.6 (Hamid, Mohmod, & Sulaiman, 2003). As bamboo grows older, G_s increase, thus Poisson ratio increases, which make it more incompressible. Modulus of Elasticity & Modulus of Rupture of the bamboo will also increase as it grows older.

The Poisson's ratio, ν is taken as 0, based on Amada and Lakes (1997). As bamboo become less dense (more porous), the Poisson's ratio will decrease.

2.3 Geotextile Parameters

The geotextile was modeled using geogrid element. The geotextile are modeled as an elastic material & the parameters for the geotextile are as shown in Table 4.

Table 4: Parameters for Geotextile Reinforcement

Parameter	Value	Unit
Axial stiffness, EA		
1) PEC100	100	kN/m
2) TS40	13.5	kN/m

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3. FINITE ELEMENT ANALYSIS

3.1 Geometry

The embankment was modeled using plane strain models, with only half of the embankment was modeled, due to symmetric reason. The dimensions of the embankment model are as shown in Figure 1.

3.2 Construction Stages

The construction stages of the embankment are modeled as shown in Table 5. The analysis was performed by considering the effect of large deformation (updated mesh), since for highly compressible soil, it is more accurate to simulate using large deformation compared to small strain. During the construction of the embankment, undrained analysis was carried out, considering low permeability of the soil and the short duration of the construction.

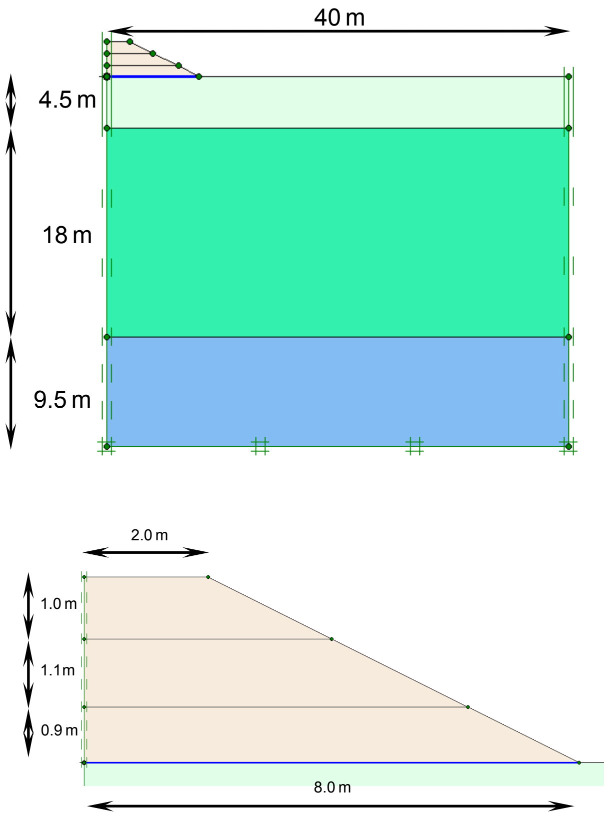

Figure 1: Geometry of the Embankment Model

Table 5: Construction Stages of the Embankment

Phase	Duration (days)
1) Backfilling the first layer (0 – 0.9 m)	5.4
2) Backfilling the second layer (0.9 – 2.0 m)	6.6
3) Backfilling the first layer (2.0 – 3.0 m)	6.0
4) Consolidation	365

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4. RESULTS AND DISCUSSION

The analysis was carried out to evaluate the vertical deformation and stability of the embankment. The vertical deformation of all three embankments is shown in Table 6. It can be seen from Table 6, after one year consolidation, vertical deformation of TE2 is lesser than for TE1 and TE3. However, the vertical deformation from simulation is lesser compared to actual deformation (Marto, Othman, Mohd Hanipiah, & Hirman, 2010), perhaps due to limitation of samples from site that had been tested for stiffness parameters (only six samples with depth up to 4 m had been tested for compressibility). Another interesting observation is vertical deformation for TE1 and TE3 is similar. This phenomenon could be explained as the only different between both PEC100 and TS40 is the axial stiffness. As in this embankment, tensional axial stress on the geotextile is not the governing stress, compared to other situation such as reinforced earth wall, where the axial stiffness will govern the situation. Furthermore, the purpose of the geotextile in this situation is as a separator. The stability of the embankment is evaluated using phi-c reduction method, where the factor of safety is defined as ratio between available strength and strength at failure. The factor of safety of all three embankments after different stages is shown in Table 7.

Table 6: Vertical Deformation for All Embankments

	Vertical deformation (mm)			
Embankment	Phase 1	Phase 2	Phase 3	Phase 4
TE1	9.83	22.42	32.86	67.92
TE2	9.49	21.38	30.42	63.93
TE3	9.83	22.42	32.86	67.92

Table 7: Factor of Safety for All Embankments

	Factor of Safety			
Embankment	Phase 1	Phase 2	Phase 3	Phase 4
TE1	9.49	5.65	4.84	5.46
TE2	15.01	6.38	5.73	5.27
TE3	9.49	5.65	4.84	5.46

It can be seen here that the Factor of Safety of TE1 and TE3 is equal, which is similar to the results for deformation. TE2 has higher Factor of Safety compared to TE1 & TE3, and this different is mainly contributed by the bending strength of the bamboo reinforcement. The different of the predicted failure mechanism can be observed in Figure 2a and 2b. However, for the long term stability, it was found that the Factor of Safety for all three embankments is almost similar and the predicted failure mechanism (as in Figure 3a and 3b) is also almost similar.

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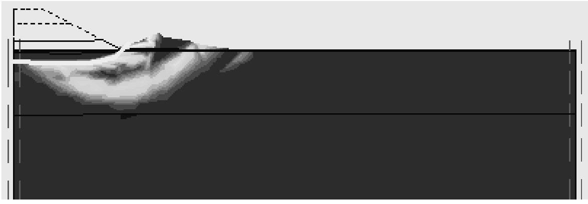

Figure 2a: Failure Plane for TE1, After Phase 1

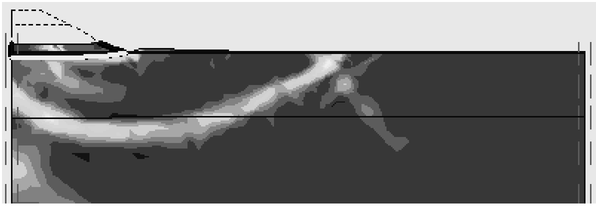

Figure 2b: Failure Plane for TE2, After Phase 1

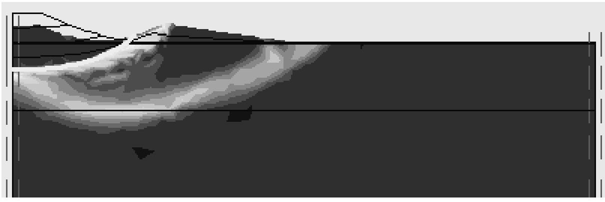

Figure 3a: Failure Plane for TE1, After Phase 4

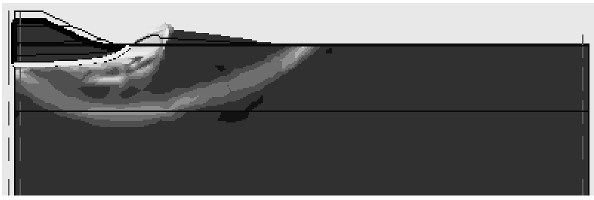

Figure 3b: Failure Plane for TE2, After Phase 4

5. CONCLUSIONS

Based on the two dimensional finite element analyses for all three embankments, these conclusions are made:

1) Bamboo reinforcement had improved the performance of the embankment by reducing probable settlement and increasing the stability of the embankment. These are due to facts that bamboo has both bending and tensile strength, compared to geotextile which only has tensile strength.

2) For two dimensional finite element analyses, TE1 & TE3 behaves similar, due to fact that for slope stability of an embankment, tensile strength of the geotextile is less significant, in comparison to other situation such as reinforced earth wall.

6. FUTURE RECOMMENDATIONS

Some recommendations on the research in the future are as follows:

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1) Three dimensional finite element analyses should be carried out, in order to properly simulate the bamboo reinforcement and the geotextile above the bamboo. The stress distribution in the bamboo and geotextile can be observed, as in two dimensional analyses the bamboo is modeled as a plate element and in plane strain analysis, only one dimensional stress distribution can be observed.

2) The effectiveness of the bamboo reinforcement in resisting dynamic loading can be simulated. As the embankment will be used as a foundation of a road, so the performance due to loading from vehicles should be simulated. Furthermore, the effectiveness of bamboo reinforcement to resist seismic load should be look upon.

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